Forest Fire and Atmospheric Sciences Research 4400

Research Work Unit FS-RM-2151

STUDY PLAN 2151-5

Measurement and Modeling of the Dispersion of Pesticide in a Forest Canopy

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PROBLEM STATEMENT AND PURPOSE

Study Plan 2121-5

MEASUREMENT AND MODELING OF THE DISPERSION
OF PESTICIDE IN A FOREST CANOPY

A major problem of research work unit (RM-2151) is to provide techniques to evaluate meteorological factors in forest management. An area where meteorology has been identified as having a significant role is in aerial application of chemical agents. The Douglas-fir Tussock Moth Program (DFTM) of the USDA is interested in finding out how meteorological information might be used to improve the effectiveness of aerial application in Tussock Moth control.

Our Study is planned as a set of individual yearly activities such that each increment will advance toward a final product. However, the annual contribution to this product is also of significance. The final objective is the development of procedures which optimize the use of meteorological phenomena in the distribution of pesticides. In order to define such procedures it is necessary to study the interaction of meteorology with pesticide distribution in a typical, hopefully somewhat idealized, Douglas-fir stand. This is the object of our first year research. A Field program will establish some of the meteorological interactions with the canopy and a cooperative effort with Research Work Unit PNW-2208 will result in measuring pesticide distribution through the canopy. Following the field season efforts will be directed to development of a mathematical model to relate deposition in the canopy to meteorological conditions and pesticide characteristics.

FY 76 efforts will be oriented toward validation of the model by measurements generally similar to those being made this year (FY 75) and to development of model-user considerations. Once a model exists which seems to represent deposition as a function of meteorological conditions its usefulness will be governed by the requirements of input data and its simplicity of use. Tabulations of meteorological scenarios with predicted deposition rates would form a final product.

STATE OF KNOWLEDGE

Pesticide drift from aerial application has generally been controlled by using large droplets which have a short residence time aloft, by spraying at low altitudes and by spraying under theinversion. On the other hand, uniformity of application has been achieved by using smaller droplets able to penetrate the tree crowns and impact on the interior foliage. These can also reach theunderside of foliage surfaces.

The balance between these two objectives involved consideration of such factors as target, drift hazard and the chemical agent. It appears worthwhile to develop a quantitative model of canopy spray penetration able to predict the average dosage at particular levels in the stand as well as the variation of dosage within the crown of typical trees. Input should be as simple as possible consisting of the wind over the canopy, site factors including stand characteristics and the method of application; eg., droplet size and density distribution, swath pattern, emission pattern, and aircraft altitude.

The literature on aerial application of aerosols to forest stands is extensive but may be roughly divided into two areas, namely; descriptive

It is anticipated this will be followed toward validation of the model by measurements generally similar to those being made this year (7) (8) and to development of model-guided recommendations. Thus a model which seems to represent deposition as a function of meteorological conditions its usefulness will be governed by the requirements of input data and the simplicity of usage (simulations of meteorological scenarios with predicted deposition rates would form a final product.

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The literature on aerial application of pesticide to forest stands is extensive but may be roughly divided into two areas, namely, descriptive

surveys of field experiments, and more quantitative studies by military agencies directed toward general models to predict subcanopy dosage levels for aerosols and suspensions in the 5 to 20μ range considerably smaller than the 50 - 200μ range of pesticide sprays.

The descriptive studies have established that for levels sites, drift is minimized by the use of inversion (stable) conditions (4, 5, 9, 13, 15, 16, 18). They also indicate an apparent random variability of dosage patterns determined by dye tracer patterns on cards at the forest floor, by the washing of tracer material from foliage surface (9, 12) and by mortaility rates of the target organism (4, 16). Some systematic differences indicated are maximum accumulations on the windward sides of individual tree crown (4, 13, 16) relative to the lee, and the interior or local accumulation maxima to the lee of clearings, and roads (4, 16).

In some instances the rationale for the use of inversion conditions conflicts with what has been recently observed in forest stands (16), since the variation of turbulence intensity within the canopy does not seem to be effected strongly by stability. Such conditions, however, are associated with low canopy air speeds (11), so that the basic practice may be valid for at least level terrain. Systematic differences indicate, however, that the net effects of advection (movement of the cloud by the wind field) and diffusion (spreading of the cloud by turbulence) are comparable to the settling motion within and above the canopy. This suggests that all three components must be included in a model. In many of these studies, the lack of data on the local collection efficiency of the devices used to collect droplet samples made the results somewhat ambiguous. For example, windward maxima might correspond to higher air speeds rather than higher droplet concentrations if foliage residue or flat plates were employed.

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[illegible] of turbulence intensity with [illegible]

[illegible]

[illegible] (1971), [illegible]

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collection efficiency of the devices used [illegible]

[illegible]. For example, [illegible]

[illegible] than higher density [illegible]

Most of the concepts and models developed and applied are designed for agricultural crops and altered for only the extreme roughness of the canopy surface. Other factors such as the unique flow field within the canopy should be considered. The military studies are not directly applicable to the pesticide problem either. The particle sizes studied were small enough that aerosol settling and interception on the canopy elements could be neglected, eg.; the analysis of Calder (5, 17). In most models the emission above the canopy is assumed to behave like a gaseous plume, while the subcanopy dosage reflects a balance between advection and vertical turbulent flux (3, 7, 17). These assumptions seem correct for aerosols smaller than 50μ since secondary maxima often occur above the canopy upwind from the original emission cloud due to reemission from the subcanopy space (3, 17). Such effects minimize appreciable sedimentation or canopy interception.

Small particle sizes also suggest the assumption that an effective exchange coefficient for the aerosol may be assumed to be the apparent eddy viscosity. Because of particle inertia this is doubtful for aerosols in the pesticide range. This assumption allows the use of a ratio between horizontal windspeed over the canopy and subcanopy speed (both measured at standard heights), (2, 6, 17), to establish a measure of the "stand ventilation rate" and thus the ratio of the above canopy dosage to the subcanopy dosage for different stands. This approach has met with some success on level terrain with small sized aerosols (2, 17). Where subcanopy density flows are prominent one would expect large overestimates (1).

The state of current technology in the modeling of canopy penetration of aerially applied pesticides is reviewed in a recent paper by Barry, Dumbault and Cramer (18). This paper presents a discussion about the uses of models along with an outline of the current Dugway-H. E. Cramer model. This model is based upon the Gaussian diffusion hypothesis (19) and its application to heavy inertial particles (20). It was "developed for application with aerial spray releases over unforested flat terrain. The generalized models have proven effective in predicting deposition and air concentration under these conditions, but have not been verified for spray applications over forest canopies."

The use of a Gaussian based titled plume model to calculate the canopy top dosage as, say, a function of drop size distribution is very useful. It, for example, allows a rather precise determination of the amount of pesticide entering the forest canopy and the location of entry. It is particularly useful for determining the amount of drift. However, relating such a canopy top dosage to a more significant parameter of spray effectiveness such as percent kill is not obvious. The behavior of the cloud of pesticide as it encounters the forest canopy must also be assessed. Consider, for example, intertialess particles which would follow fluid motion entirely. Such particulates would never deposit on any surface. Real particles will in fact deposit through a combination of gravitational settling and more generally impaction due to the difference between particle motion and fluid motion (21, 22).

In order to access this impaction removal, it is necessary to consider the detailed behavior of flow in the canopy. Bergen (23, 24) has developed a theory of the momentum distribution in a forest stand. Fritschen and

coworkers have provided data for the subcanopy distribution (25). Figure 1 shows the Bergen (23) lodgepole pine canopy wind distribution plotted against some profiles from Fritchen. A recent review by VanLiere and Barry (26) discusses a number of techniques to calculate aerosol deposition on forest foilage. Most of the work is based upon theoretical calculations of impaction efficiency of various sized aerosols on idealized cylindrical surfaces. The authors point out that while the theory is generally available data to access the effectiveness of various models is strongly needed.

STUDY OBJECTIVES AND HYPOTHESIS

Our Study is based upon the establishment of a few hypothesis which will be subjected to field investigation. They are:

1. Material sprayed from an aircraft can be related to an above canopy concentration by the application of a tilted gaussian plume with inertial particle fallout.
2. The ratio of above canopy concentration to canopy penetration depends only on U_* and the droplet inertial parameter.
3. The ratio between canopy dosage and floor dosage depends on U_*, a canopy density parameter, and the droplet inertial parameter.
4. The distribution of dosage with height depends only upon U_* and canopy foiliage characteristics.
5. The distribution of dosage with downwind distance at any level depends upon (U_*), (L), and the C_D.

MEASUREMENT PROGRAM

The measurement program of phase 1 will be conducted in late June through July, 1975. Measurements will be made primarily from a tall tower established above a mature Douglas-fir stand. Meteorological data will be

collected for a period of time along with deposition and impaction data resulting from specific aerial applications.

Specific components of the measurement program follow:

I. Site

A. Location

The site is located at Gnat Flats on the Wenatchee National Forest approximately 35 km south of Cle Elum Washington.

B. Topography

The site is at the top of a shallow dome with grades of 5% or less. There are no nearby terrain features which could be expected to interfere with the prevailing westerly winds or which could generate appreciable terrain induced flow.

C. Vegetation

The stand is a mixture of second growth Douglas-fir with some Grand-fir. Average tree height for the Douglas-fir is 26 meters with isolated trees attaining heights of 40 meters or more. Dbh appears to be of the order of 20 cm. Stem spacing is about 7 meters with extreme variation.

There is no clearly defined subcanopy space. The stand is interspaced with small openings of the order of a tree height or more and line crowns extend almost to the floor at the borders of these openings. In the areas remote from such openings the line crown appears to start at about 20 meters height.

II. Meteorological Instrumentation

A. Anemometers

Anemometers used will be Gill orthogonol propeller vane assemblies. These instruments have a predictable and linear response at very low speeds,

i.e., less than 50 cm/sec. where vane response is poor.

This configuration also allows a test for edge effects and the assumption of uniform flow at the anemometer level by measurement of the vertical motion. Threshold velocities are of the order of 10 cm/sec. for the version to be used.

Since these instruments responded to turbulence of very low scales, i.e., 20 cm, the output from the horizontal components will be read and recorded through an RC averaging circuit with an equivalent time constant of about 5 minutes. The same smoothing will be applied to the vertical velocity outputs in the uniformity tests mentioned above.

Anemometers will be mounted on 2 meter arms extending out from the tower lattice towards the west (the prevailing upwind direction).

Arms will be located at approximately 27, 29, 31, 33, 35 and 37 meters above the ground (avg. tree height, 26 m).

B. Air Temperature Sensors

Air temperature will be measured with bead thermistors mounted in ventilated radiation shields at each of the anemometer levels. The thermistors are connected to bridge circuits whose imbalance voltage is recorded at the data acquisition unit. Thermal lagging is raised from the bead value; i.e., about 1 sec. at 25°C, to about 2 minutes by drops of epoxy cement added to the bead.

Thermistors will be located on the same arms as the anemometers.

C. Data Acquisition System

1. The basic data collection unit is an Esterline-Angus D2020 Digital Datalogger. The unit can scan any consecutive group of up to 20 analog signal voltages at speeds of 2.5 channels per second and with adjustable ranges from 2 to 200 MV.

Digital output may be taken from an attached mechanical printer and a Kenedy digital tape recorder.

2. Power requirements will require a gasoline powered generator, a battery charger, two large Nicad 6 v batteries and a Nova 12 v inverter. The AC power needed to operate blowers in the anemometers and the thermistor mounts will be supplied directly from the generator. The DC voltage used for the thermistor bridge circuits will be from the batteries. The tape recorder and the D2020 will be operated with the stabilized AC output of the Nova inverter.

3. The data acquisition equipment will be housed in a 15 ft. trailer next to the reference tower. Butane heating will be used to provide the needed environment for the equipment.

D. Tower

1. The reference tower will be a crankup 40 meter tri-ex tower with the GUY guy lock system. This design allows instrumentation to be placed on the top 13 meters of the tower before the tower if fully raised.

2. The top tower section will be leveled using photoelectric remote reading levels after full erection.

3. All tower sensors will be connected by cable to the instrument trailer.

4. The tower will be conventionaly guyed with temporary auger type anchors and on a 1 x 1 x 1 meter concrete base.

III. <u>Impaction Instrumentation</u>

Droplet deposition will be measured on Kromecoate cards mounted on a twin cylinder array. The impactor consists of an empty aluminum 12 oz. beverage can (A) and a 2.4 cm diameter by 14 cm long styrofoam cylinder

(B) suspended on a wire coathanger. Cards will be attached to both cylinders with rubber bands. A spring paper clip is used to attach the hanger to a line.

The collection efficiency (E) for a cylinder may be defined as the ratio of the number of droplets collected by the cylinder per unit length to the flux of droplets far upstream of the cylinder resolved to the plane perpendicular to the axis of the cylinder multiplied by the diameter of the cylinder. In general, E is a function of the air speed component normal to the axis, the droplet size and mass, and the cylinder diameter. For oil droplets in the 50 to 100μ range the ratio of E for the larger cylinder to that of the smaller cylinder varies smoothly with wind speed falling to about 0.5 at a speed of 100 cm/sec. This card deposits yielding the effective approximate ventilation rate during the cloud drift near the impacter. This value can be used with the absolute value of the droplets intercepted for a particular size range to estimate the average air borne droplet concentration at the impactor location for a particular droplet size.

Droplet concentrations and size distributions from the cards will be analyzed by the Corvallis project using the Quantimat at that location and the techniques developed by that group.

IV. <u>Measurement Details</u>

A. Grid Layout

A rectangular grid with spacings of 67 meters has been laid out with stakes. Orientation lines North-South, East-West. The total grid is 333 meters on a side.

The tower location will be at approximately the Northwest corner of the grid.

The measurement locations total 36 corresponding to the nearest two trees for each grid intersection. Trees will be chosen such that

(1) the tree (A) will be that closest to the intersection which is average height or greater,

(2) the tree (B) will be the nearest tree to (A) along a N-S azmuth meeting the same requirements.

B. Deposition Measurement Distribution

1. Deposition measurements will be made with impacters at 24 meters, 22 meters, 20 meters, 18 meters, 9 meters.

2. Vertical arrays of impacters will be located in triods. Of each triod one array will be located between trees A and B. The other two will be through the canopies of tree (A) to the south and tree (B) to the north with impacters at 24, 22, 20 meters only.

3. Impacters will be suspended from cards through pulleys.

4. Conventional deposition measurements will be made below all vertical arrays and at the intersections of the measurement grid

C. Measurement Routine During Spray Runs

1. Deposition measurements will be made only when the average wind direction at the 35 m level on the tower lies in a westerly quadrant.

2. During sprays the tower measurements will consist of smoothed horizontal wind components at one minute intervals and the air temperature profile at one minute intervals.

3. The spray treatment will consist of multiple passes along a line of the measurement grid emitting the fine spray and the coarse spray simultainously.

4. Before spraying, the impactors will be loaded and raised at all locations. Cards will be removed 30 minutes after the end of spraying.

5. Spray treatments will be made along each line for a high speed and low speed condition.

a. Low speed conditions will be anticipated for morning hours high speed conditions for late morning or afternoon situations.

D. Canopy Character Stress Measurements

For These measurements tower output will be recorded in three distinct formats:

1. Uniformity Test

Tower and output will consist of time smoothed vertical velocity output at all levels and horizontal components at the top level. Output on paper and tape.

2. Roughness Estimate

Tower output will consist of air temperatures, and smoothed horizontal components at all levels.

3. Vertical Gustiness

Tower output will consist of air temperature at three levels smoothed horizontal components at two levels and smoothed instantaneous vertical velocities at all levels.

Roughness and gustiness measurements will be made through the day.

MODEL DEVELOPMENT AND VALIDATION

The model will attempt to provide a mass balance of material emitted from the spraying aircraft. Such a determination of the distribution of pesticide will allow, after it is validated, a prediction of the amount of pesticide distributed into various compartments of the atmospheric-forest canopy system. In general, we consider three seperate compartments namely atmospheric transport (drift), canopy interception, and ground level interception. Consider the mass of material emitted from the aircraft to be distributed as a line source. The emission is defined as

$$Q_o = \text{mass/length-time} = \text{gr/m-sec}$$

the concentration at any point at any time is

$$\chi = \text{mass/volume} = \text{gr/m}^3.$$

Assuming that data are available regarding (a) the total amount (mass) of material released, (b) the number of swaths flown and (c) the length of each swath, it will be possible to calculate the emission Q_o. Deposition data analyzed with the model can offer a check on this calculation.

I. Above Canopy Diffusion

The gaussian formalism is perfectly adequate to treat diffusion from a concentrated source. The difficulty in developing a model comes in the specification of the meteorological input and in specific in the determination of the diffusion coefficients. The gaussian formalism for a line source consists simply of assuming that the shape of the diffusing cloud is a gaussian distribution in the vertical and horizontal directions so that the concentration χ is given by (20).

$$\chi = \frac{Q_o}{2\pi\,\sigma_x\,\sigma_z}\left\{\exp\left(-\frac{(H-z)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(H+z)^2}{2\sigma_z^2}\right)\right\}\exp\left(-\frac{(x-\bar{u}t)^2}{2\sigma_x^2}\right.$$

where σ_z = standard deviation of the plume in the vertical direction

σ_x = standard deviation of the plume in the along wind direction

X = distance downwind from the source

Z = distance above the ground

$\bar{u}$ = mean cloud transport times

t = time after cloud stabilization

Consideration of edge effects, namely the finite length of the source, is included by multiplying equation (2) by

$$(3)\quad \frac{1}{2}\left\{\operatorname{erf}\left(\frac{L/2+Y}{\sqrt{2}\,\sigma_Y}\right)+\operatorname{erf}\left(\frac{L/2-Y}{\sqrt{2}\,\sigma_Y}\right)\right\}$$

where L = length of the crosswind release line

y = laterial distance from cloud centerline

σ_y = standard deviation of the crosswind concentration for a point source

The actual concentration at any time above the canopy must also include a depletion factor for graviational setting. Following the work of VanderHoven (19) (Chapt. 5) and others Cramer et al., (20) calculate the factor to be, assuming that the depth of the surface mixing layer is sufficiently high so that no pollutants are reflected off the inversion

$$(4)\quad \exp\left(-\frac{(H-V_s x/\bar{u}_H-z)^2}{2\sigma_z^2}\right)$$

where V_s = gravitational velocity for a given particle size

$\bar{u}_H$ = mean wind speed between receptor and H

The concentration above the canopy may be calculated by the product of equation (2) with (3) and (4). This equation represents the diffusion of a gravitational settling material of uniform size. It may be applied either for specific drop sizes (i.e., fall velocities) or for an assumed mass fall velocity. Both these approaches will be persued.

Another point regarding equations (2) - (4) is that of the time interval involved in the diffusion. This is usually treated by consideration of a total dosage to the canopy so that the appropriate equation is integrated over time to calculate the accumulation. The deposition at the canopy top, H can be calculated using the equations considered above. If we call the canopy top deposition S_H, it becomes

$$(5)\quad S_H = \frac{f_i Q_o}{\sqrt{2}\,\pi}\left(M+N\right)\left\{\frac{1}{2}\left[\operatorname{erf}\left(\frac{L/2+Y_H}{\sqrt{2}\,\sigma_{Y_H}}\right)+\operatorname{erf}\left(\frac{L/2-Y_H}{\sqrt{2}\,\sigma_{Y_H}}\right)\right]\right\}\exp\left(\frac{-kX_H}{U_H}\right)$$

M, N = M, N (X_H, U_H, σz_H, and the vertical atmospheric diffusion coefficient given in (20)

$$X_H = R \cos \phi_H$$

R = radial distance from the source to receptor

$$\phi_H = |\bar{\Phi}_H - \theta_R|$$

Φ_H = angle between mean wind direction at H and a line connecting the source and the point at which the cloud centroid of particles having a setting velocity of V_S intersects the canopy

θ_R = angle between the mean wind axis and a line connecting source and reception

t_i = fraction of pesticide with a fall velocity given by V_S.

The details of this calculation have been programmed for the use of the Army and we are in the process of obtaining the computer codes. Some modifications will need to be made for the change of deposition surface from the ground surface to the canopy top.

Determination of the meteorological and plume parameters will be with a combination of measurements and analytical techniques. Although it is always preferable to measure quantities rather than calculate them, a number of techniques are available to relate simple meteorological observations to the values of σ. An example is given by Smith (28) which allows the calculation of Pasquill stability class by measuring an empirical sunlight factor relating this to upward heat flux and a measurement of wind speed. This will only be necessary if measurements from the meteorological tower are unavailable. There are, as well, a number of other techniques available to calculate such parameters, (19, 20).

II. Canopy Deposition

A general indication of the average distribution of horizontal wind in various forest canopies is shown in figure 1. Aerosols which penetrate below the canopy level are subject to the presence of vegetation, needles and limbs. An aerosol larger than about 30μ has a reasonable probably of being impacted. Since the object of Tussock Moth control spraying is in fact in canopy impact, a model is necessary to calculate the efficiency of the impaction. Such a model has not yet been developed. U. S. Army literature refers to a classified model of aerosol penetration (29) based upon principles similar to the extinction of radiation in a forest (30). A limiting assumption of this model is that all size fractions of aerosol are treated equally which is not physically realistic.

A somewhat more sophisticated treatment is used by the Dugway group based on work done Johnstone et. al. (31) as an adaptation of the Gaussian diffusion model to forest canopy impaction.

Fuchs (22) points out the limitations of the Johnstone (31) work and suggest the need for a more fundamental approach. Consider, following Fuchs (22), the concentrations equation for falling mass,

(6) $$U \frac{\partial \chi}{\partial x} - V_s \frac{\partial \chi}{\partial z} = \frac{\partial}{\partial z} \left(K \frac{\partial \chi}{\partial z}\right)$$

where U is the velocity in the canopy given according by Bergen (23) as $U = U_* f(z/z_o)$ and the particular form of f depends upon canopy type, V_s is the particle fall velocity, K is the within canopy dispersion coefficient. The determination of K is extremely difficult, however, some recent work in second order turbulence theory (32) suggests that K can be related to various dimensionally consistent groups involving the turbulent dissipation ε. In analogy to flow through porous media and considering Bergen's (24) momentum analysis for the canopy, one might consider K of the form

(7) $$K \propto d^3 \varepsilon^{1/3}$$

where d is a characteristic dimension of the canopy. Where β is the posousity of the medium in question, a dependence on this parameter should be included.

Equation (6) can be solved using either numerical or analytic methods depending upon the selection of parametric functions.

The material remaining after the above canopy and within canopy models have been applied will be considered the surface deposition.

PRESENTATION OF RESULTS

The basic data resulting from the measurements will be made available as an internal report. The presentation will consist of the estimated

airborne droplet concentrations, as a function of droplet size, distance from swath position, level, the Richardson's number above the canopy and the surface shear stress above the canopy. Estimated stand characteristics will be appended.

The results of numerical simulations based on the field data will be presented as publications in the appropriate technical journals.

Implications for further research efforts and if possible for operational techniques will be presented via internal reports.

COOPERATIVE EFFORTS

Cooperation with the Aerial Applications Project, PNW 2208, at Corvallis.

During the field spraying experiments in the Blueitt pass area local canopy wind direction, speed and vertical temperature gradient will be measured on selected plots using a portable mast carrying sensitive cup anemometers, wind vane and thermistors. Wind records and temperature data during and immediately after spraying will be available to assist in the correlation of deposit characteristics with droplet size and delivery system parameters.

The spray applied during the deposition measurements at Gnat Flats will be from the Aerial Application's Project delivery system.

Evaluation of all spray deposit cards will be made by the Corvallis project using the techniques and equipment developed by that Project.

Personnel will be borrowed from the Corvallis Project during equipment installation and the spray measurements.

SCHEDULE

A. Site Preparation

June 29 - July 13

During this period the measurement grid will be staked out and three pairs chosen and labeled.

The reference tower will be errected and wired.

Impactor array fixtures will be installed on the tree pairs.

B. Instrument Emplacement and Field Check

July 14 - July 18

During this period the anemometers will be deployed and leveled. The instrument trailer will be connected with data acquisition system and power supplies.

Instrument systems operated.

C. Spray Operations

July 19 - July 26

Dye applications made to plot at selected periods. Canopy aerodynamic measurements will be made on a continuous basis.

D. Vegetation Survey

July 26 - August 1

Stand characteristics to be measured. Instruments removed. Site clean up.

E. Past Calibration and Data Processing

Impactor calibration will be carried out.

Deposit card analysis.

Tower data processing.

Work will be done at Fort Collins and Corvallis.

ESTIMATED COSTS AND PERSONNEL

The principle investigator for this study is Dr. James Bergen. He will be assisted by Dr. Douglas Fox, Projet Leader in all phases of the study but most especially in the modeling and validation activities. Two technicians will be assigned full-time for May-July to the study.

Deposition Analysis

The deposit on the impactor cylinders may be approximated by

$$\text{(Ia)} \quad \frac{dD}{dt} = (\psi \chi U_N + V_s \chi)d$$

where d = the cylinder diamter

χ = the volume concentration of the droplet in a particular size range.

U_N = the local air velocity component perpendicular to the cylinder axis.

ψ = the collection efficiency of the cylinder for the particular droplet size and density

t = the time

V_s = the fall velocity for the particle.

In the above, the flux of droplets to the cylinder surface by diffusion i.e., by very small scale motions has been neglected.

The collection efficiency for the particular droplet size and mass is a tabulated function of U_N either from the numerical results of Longmuir and Bladgett and later studies or from emperical measurments found in the literature.

If we assumed that U_N is constand during the time interval of deposition.

$$\text{(Ib)} \quad \frac{D}{d} = (\psi U_N + V_s)\int_o^t \chi dt$$

or

$$\text{(Ic)} \quad \frac{D}{d} = (\psi U_N + V_s) S$$

where S is the local dosage as conventionally defined and arising as an output parameter in models for canopy aerosol penetration.

If the large cylinder is noted by a subscript (1) and the small by (S)

$$\text{(Id)}\quad (D/d)_1 / (D/d)_S = \left(\frac{\psi_1 U_N + V_s}{\psi_s U_N + V_s}\right)$$

$$\text{(Ie)}\quad (D/d)_1 - (D/d)_s = (\psi_1 - \psi_s)\, S\, U_N$$

Equations (Id) and (Ie) can be solved by simple iteration together with the numerical tabulation of (ψ_1), (ψ_s) as functions of U_N to yield estimates of V_s, U_N. For droplets in the 100μ range the theoretical value of V_s can be used. The corressponding dosage estimate (S) follows from (Ic) above applied to the larger cylinder.

The approximate analysis assumes that the sedimentation flux to the cylinder can be assumed to be independent of the impaction flux, i.e., that the sedimentation velocities are small relative to the local air velocities to the extent that effect of the latter on the droplet drag term may be neglected. Theoretical calculations of χ for droplets with an initial velocity relative to the upstream fluid do not seem to have been tabulated.

ESTIMATED COSTS

	Cost
1. UVW Anemometer assemblies @ $754 ea. (6)	$4,524
2. Net Radiometer	400
3. Steel web crank up tower with assembly	2,000
4. Cable and associated hardware	600
5. T. V. Antenna @ $100 ea. (2)	200
Equipment on hand to be used:	
1. D2020 EA Data logger system and recorder with periphial equipment	------
2. Gasoline generator	------
3. Trailer or other instrument shelter	------
4. EA dual channel recorders (2)	------
5. Bridge circuit interface	------
6. Blowers with bead thermistors $20 ea.	100
7. Portable wind recording system	------
8. Sensitive cup anemometers (2)	------
Total	$7,824

Travel and Per Diem

Salary - technician 2 months @ $1,000 mo.	$2,000
Travel - 6 round trips, Ft. Collins-site @ $250 trip	1,500
Per Diem - 60 man days (2 people @ 30 days ea.)	1,500
Vehicle use (estimated @ $2.50 day + .10 mi.)	300
Total	$5,300
TOTAL COST	$13,124

FY 76 Extension

Salary - technician 1 month @ $1,000 mo.	$1,000
Travel - 2 round trips	500
Per Diem - 60 man days (2 people, 30 days ea.)	1,500
Vehicle use	200
Total	$3,200

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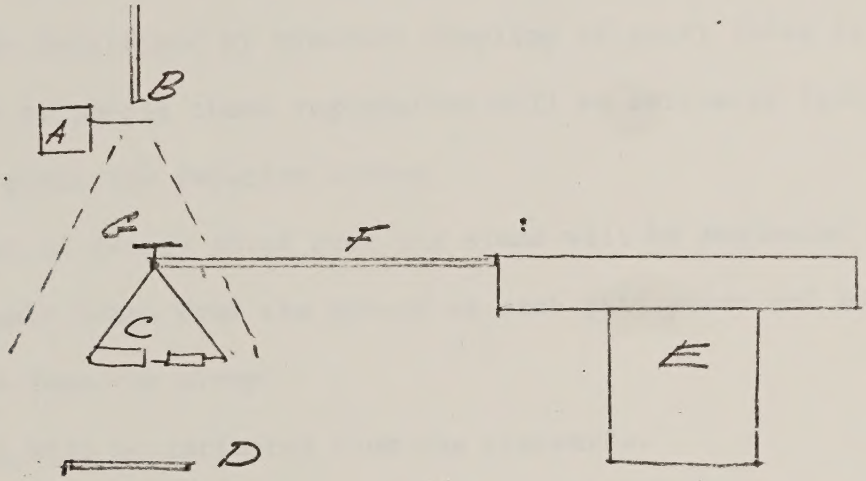
APPENDIX I

Impactor Calibration

The purpose of the calibration is to determine the deviations of the cylinder collection effeciencies from the Longmuir-Blogett function due to intercylinder interaction, appreciable fall velocities and cylinder interaction.



The setup is indicated in the schematic above The impactor (C) is mounted at a fixed angle θ to the arm F by a screw clamp G. The arm is attached to a rotating dish assembly driven by variable speed motors capable of producing rim velocities (U) from 5 cm/sec to 500 cm/sec. The arm is rotated through the spray produced by a pressurized hypodermic needle (B) interupted by the vibrator (A). The droplet size distribution in the spray is assessed in the conventional manner using the deposit card at (D).

Collection efficiencies for each cylinder of the impactor will be determined for values of θ to 0 to 45° in steps of 2° and at speeds from 5 cm/sec to 200 cm/sec in steps of 10 cm/sec. The resulting calibration will be used to correct the field measurement.

APPENDIX II

Vegetation Survey

The average foliage density distribution for the stand will be estimated from the dbh, height and line crown length using the regressions developed by Story and Fors.

The joint frequency distributions of each of these variables stratified by species will be determined by transect sampling of every fifth tree. Stem taper needed to supply these regressions will be estimated from the trees climbed to place the impactor arrays.

The variation of canopy cover over the stand will be estimated from vertical photographs taken from the ground at each grid point and below each between tree impactor array.

Tree spacing will be estimated from the transects.